PERFORMANCE OF SMALL WIND-ELECTRIC SYSTEMS FOR WATER PUMPING

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ABSTRACT

Water pumping systems for livestock and domestic uses normally require at least 500 W of power, but sometimes range up to 2000 W in size. Small wind systems can easily meet this power demand as proven by the large number of mechanical water pumping systems installed over the years. However, poor reliability because of high maintenance and aging equipment has caused many water users to seek other energy sources to power their pumps. The USDA-Agricultural Research Service has been testing stand-alone wind-electric water pumping system for livestock or domestic water users. Each systems was operated at several pumping heads and the performance evaluated for over 700 hours of operation at each pumping head.

The wind speed at which water pumping was initiated was dependent on the pumping head. Using a 1500-W wind turbine, with a head of 17 m, water began flowing at a wind speed of 3.5 m/s. When the pumping head was increased to 59 m, a wind speed of 5.0 m/s was required to initiate flow. In all cases, the wind turbine reached it maximum pumping rate at a wind speed of 13 m/s when the wind turbine began to furl and the rotor slowed. Average daily water pumping rates were calculated using monthly histograms from 10 years of wind speed data. Daily rates ranged from a high of 16,140 L/day in March to a low of 7,350 L/day in August. The average for the year was 12,530 L/day. This would be enough water for a herd of 100 to 125 beef animals.

A 1000-W wind-pumping systems studied used light wooden rotor blades which did not have much inertia when rotating; therefore, when the pump was connected to the wind turbine, the rotor stalled similar to dynamic braking. Several unsatisfactory attempts were made to alleviate this starting problem. I am recommending that a weighty rotor be used in these independent systems that would provide sufficient inertia for pump motor starting.

INTRODUCTION

Traditionally man has supplied water for their domesticated livestock by using springs, flowing streams, and handdug wells. In the late 1800's, the American multibladed windmill was developed to pump water from deep wells. These systems provided a year-around water supply and allowed for the settlement of the area known as the Great Plains. With the deployment of electrical utility systems into rural America, many of these mechanical windmills have disappeared. However, an adequate year-around water supply is still a major stumbling block to livestock grazing in many arid areas. Ranchers have found that if sufficient watering places are not provided, livestock do not move to areas of the pasture where grass may be abundant. Cattle will graze about one kilometer from a water supply; therefore, several water supplies are needed in most large pastures.

Over half of the population of rural areas of the world do not have a safe and dependable water supply. Many of these people depend on surface waters that are polluted and harmful to their health. Water can not be pumped because often times energy and labor for servicing engine-driven pumps is unavailable. The costs for new electrical service are often prohibitive. New developments with electrical generating wind machines have provided a new potential for pumping water in remote areas with wind energy. A new wind-electric water pumping system for remote areas has been developed by the USDA-Agricultural Research Service, Bushland, TX. Two of the commercial units that are being marketed in the United States were compared during 1993-94.

DESCRIPTION OF SYSTEMS TESTED

The wind-electric water pumping systems used in these tests had several things in common. The electric generators were direct-drive, permanent-magnet alternators with a 3-phase, 240 V, AC nominal output. The alternators produced a frequency and voltage that was proportional to the rotational speed of the rotor. Each system had the ability to run unloaded and had a mechanical rotor overspeed control. The three-bladed unit furled sideways out of the wind flow like a conventional mechanical windmill which resulted in a slowed rotor. The two-bladed unit furled by tilting up out of the wind flow which caused the rotor to slow. The 3.05-m diameter, three-bladed rotor unit was manufactured by Bergey Windpower[1]. The rotor blades were constructed of pultruded fiber reinforced plastic and operated at rotor speeds between 100 and 500 rpm. The 2.75-m diameter, two-bladed rotor unit was manufactured by World Power Technologies[1]. The rotor blades were constructed of aspen wood and operated at rotor speeds between 75 and 750 rpm.

Each wind pumping system was controlled by an electronic circuit that sensed the frequency and switched a standard motor solenoid which provided electric power to the standard electric pump motor. The larger, 3-m rotor machine was rated at 1500 W and was connected to a 1125 W electric motor and pump. The 2-m rotor machine was rated at 1000 W and was connected to a 500 W electric motor and pump.

The pumps used in this study were multistaged submersible pumps powered by three-phase, 240 V standard submersible electric pump motors. Pumps and motors operate at 3450 rpm when powered at a constant 60 Hz. Both systems were operated at several pumping heads to determine the wind speed at which pumping was initiated and the rate of flow at maximum rotor speed.

[1] The mention of manufacturers names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

Data for these tests were collected by totalizing the pulses from the hub-height wind speed, water-flow rate, and electrical frequency for 10 sec and averaging these data for one minute. Water-discharge pressure, water depth (total pumping head), electrical frequency, and electrical voltage were sampled at a rate of one sample per second and averaged for one minute. The one-minute averages were recorded on microdataloggers and transferred from data modules to PC's for processing and analysis. Data were sorted by the method of bins using wind speed. The bin-width was 0.5 m/s. Wind speed bins between 2 and 13 m/s usually had over 1000 samples (minutes of data). Average values and standard deviations were calculated for each bin. Standard deviations were typically less than 10% of the average values.

RESULTS

The premiss for the wind-electric water pumping system is to allow the wind turbine to operate at variable speed; thus producing a variable-frequency, variable-voltage system that can supply electric power directly to a standard electric motor. The permanent-magnet alternators would nominally produce 3-phase, 240 V AC power at 60 Hz. The 1500 W generator system produced a frequency between 0 and 70 Hz. The corresponding voltage was between 0 and 270 V as shown in Figure 1. The controller was set to connect the pump motor at a frequency of 35 Hz. The voltage rise was delayed because of the voltage drop at start-up of the motor. At a wind speed of 6.0 m/s, the system was stabilized and the voltage and frequency ramped-up together until the rotor furled at a wind speed of 13.5 m/s. The benefit of this type of system is clearly shown in Figure 2 where the voltage-frequency ratio (V/R ratio) is shown. The V/F ratio exceeds 3 at 6.0 m/s wind speed and remains almost constant until furling at 13.5 m/s wind speed. The electric motor rated at 240 V at 60 Hz

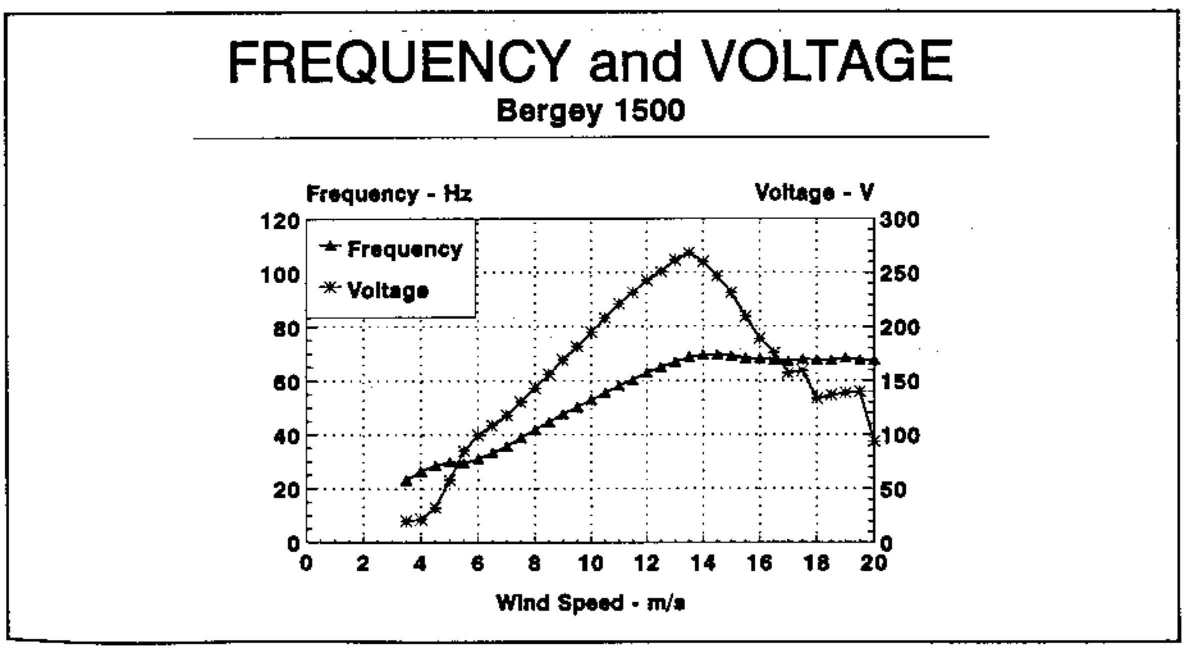

Figure 1 Measured frequency and voltage from a 1500 W wind turbine for each wind speed bin for a pumping depth of 45 m.

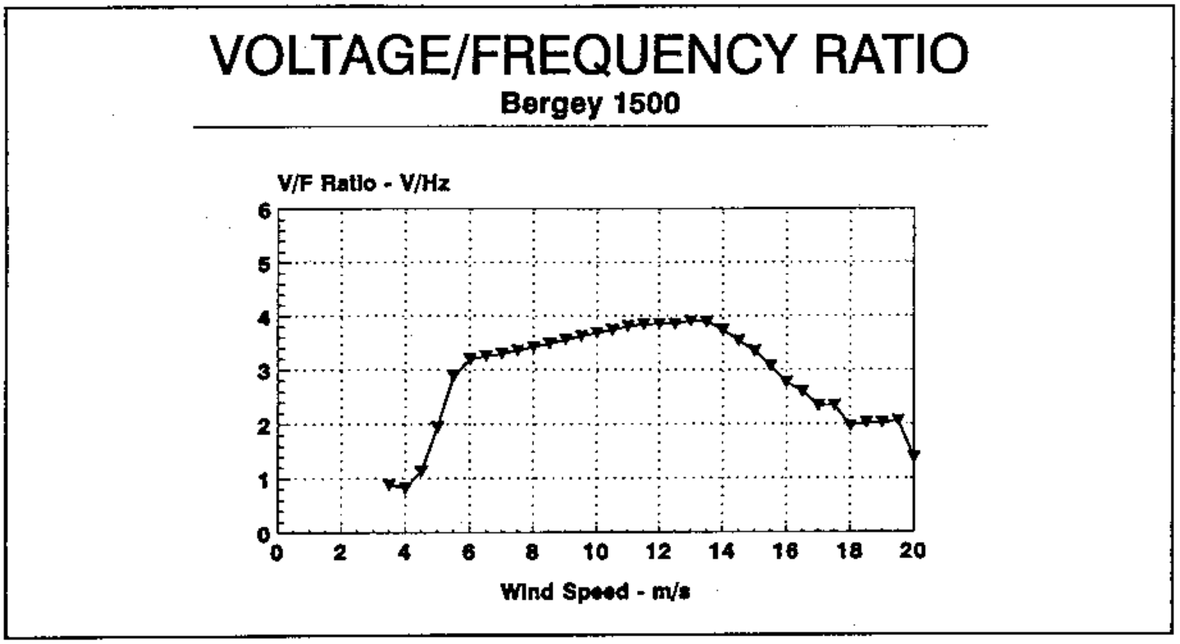

Figure 2 The voltage/frequency ratio for a 1500 W wind turbine while pumping from a depth of 45 m.

likes to have a voltage-frequency ratio of near 4.0. Although, the V/F ratio varied from 3 to 4, this is in the acceptable range for most motors. When the V/F ratio is constant, the current draw to the motor is proportional to the power provided to the motor and is always equal or below the design current; thus not causing motor overheating.

The pumping rates for four pumping heads are given in Figure 3. Three additional pumping heads were tested, but were removed from the chart for clarity. For the 17 m pumping head, flow was initiated at a wind speed of 3.0 m/s and a peak flow of 40 Lpm was recorded at a wind speed of 12 m/s when furling occurred. The wind speed when flow was initiated varied from the 3.0 m/s at a head of 17 m where the flow was 2.5 Lpm to 4.0 m/s at a head of 52 m where the flow was 1.2 Lpm. The peak flows varied from 36 to 41 Lpm for all heads tested. The flow curve for a head of 45 m was selected for conducting a prediction of yearly pumping. Monthly wind speed histograms from 10 years of wind speed data collected at a height of 10 m at Bushland, TX was used to calculate an average daily pumping volume for each month. The results of this analysis are shown in Figure 4. The highest daily average water pumped was in March with a volume of 16,139 L/day and the lowest was in August with a daily volume of 7,349 L/day. The average for the year was 12,534 L/day and all months, except August, exceeded 10,000 L/day. A beef cow requires 40 to 50 L/day; therefore, this pumping system would provide for well over 100 head. I suggest that a rancher plan to have a storage tank that would hold a five day supply and that the herd be sized for the lowest daily amount available. However in this case; a rancher might choose to select the average of July, August, and September or 9,680 L/day as his available water supply.

The voltage and frequency for the 1000 W wind turbine when pumping against a lift of 45 m is shown in Figure 5. The controller for this system was preset to engage the pump at

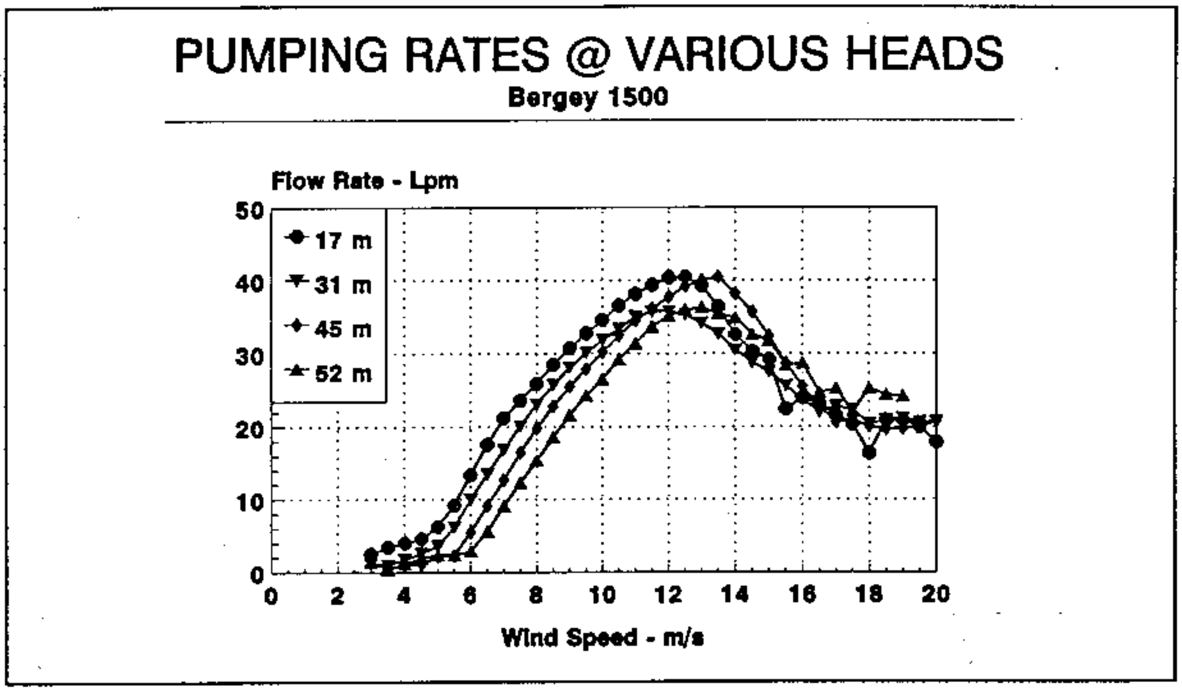

Figure 3 Water flow rates for four pumping depths using a submersible pump and a 1500 W wind turbine.

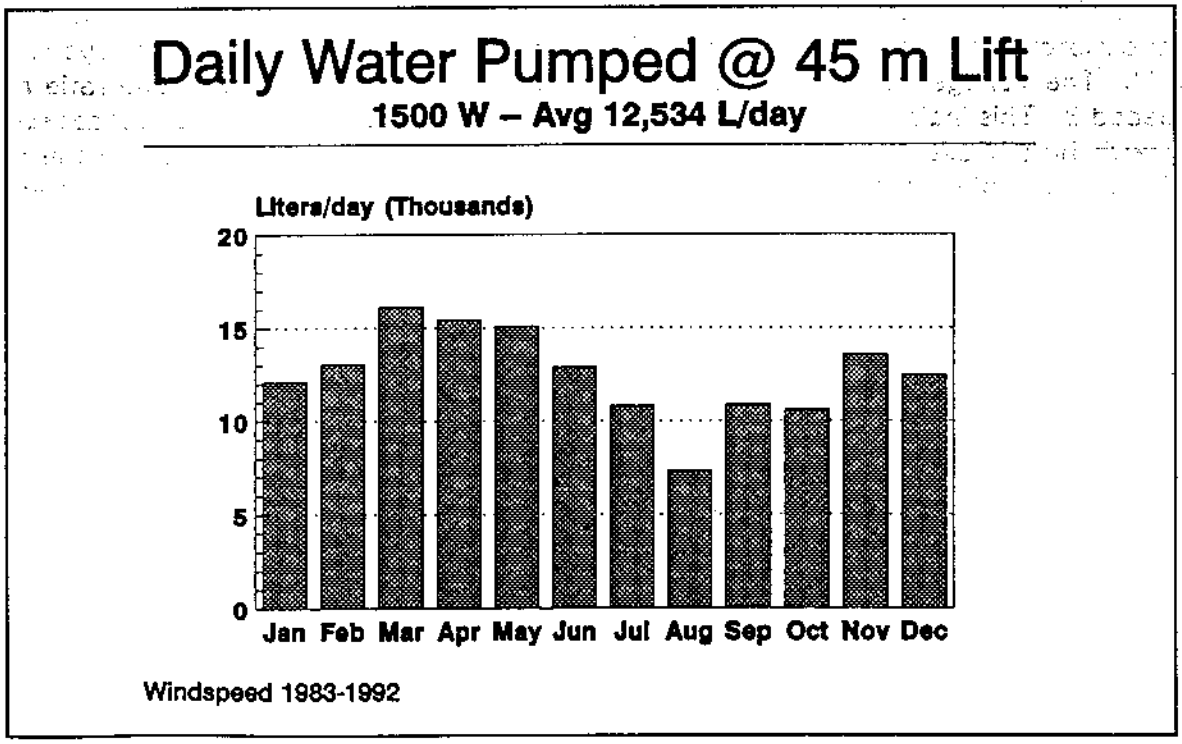

Figure 4 Average daily water volume pumped for each month calculated using 10-yr wind speed histograms from Bushland, TX. The pumping lift was 45 m.

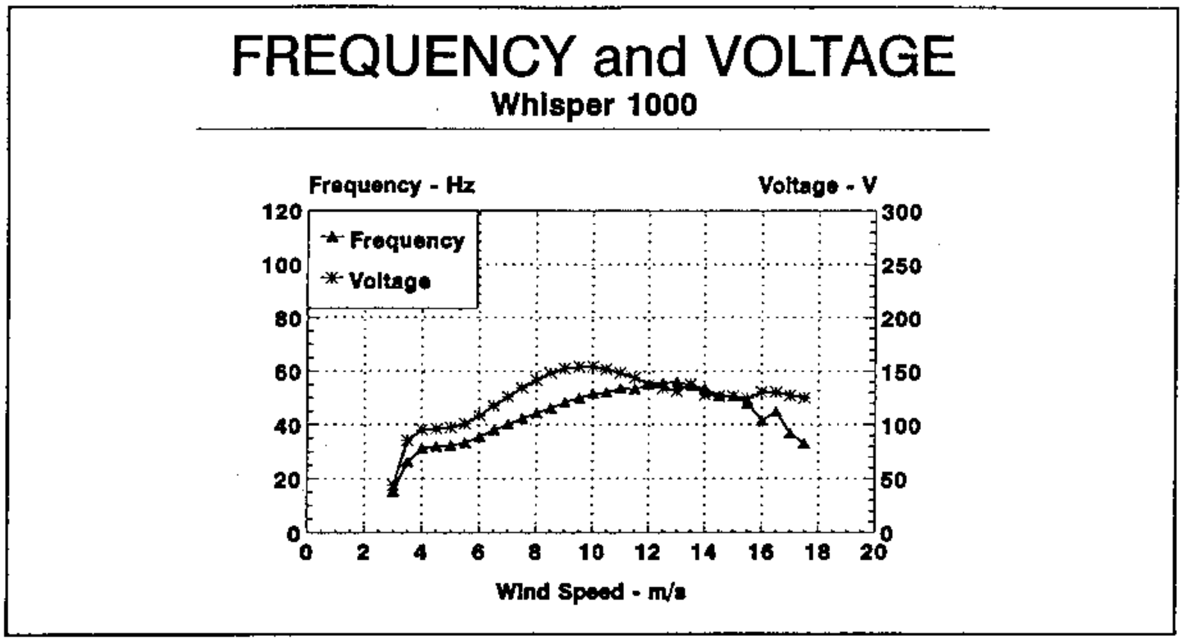

Figure 5 Measured frequency and voltage from a 1000 W wind turbine for each wind speed bin for a pumping depth of 45 m.

approximately 30 Hz, but the voltage was too low to consistently provide enough torque to start the electric motor. We first tried a 750 W, as recommended by the manufacturer; but the pump motor would stall the wind turbine more than it would start. With the 500 W electric motor, the system would start at 5.5 to 6 m/s wind speed after the voltage exceed 100 V. The voltage/frequency ratio for this system is shown in Figure 6 and ratio rarely exceeded 3. This indicated that the system needed to produce more voltage to match to the standard three-phase electric motors. Recently, we replaced the alternator on this wind turbine and the new system provides a higher voltage and thus a higher voltage/frequency ratio. We have not collected enough data to be presented in this paper. When the frequency exceeded 50 Hz, the system did not continue to produce sufficient power and the pump acted as dynamic brake causing the systems to slow or stop. A heavier rotor would provide more inertia, which would keep the system operating nearer optimum.

The water pumping performance for this wind turbine is shown in Figure 7. The flow did not consistently begin until the wind speed exceeded 5.5 m/s. At a wind speed of 5.0 m/s, the system was off with no water flow, three times as much as it was on. Personal observations clearly showed that the unit would not consistently start. The maximum water flow was much less than anticipated from the pump tests at 60 Hz utility power. The low flow is attributed to the low frequency and voltage. Again, this appears to be corrected with the new alternator. Because the flow seems below normal, no average daily water volumes were calculated.

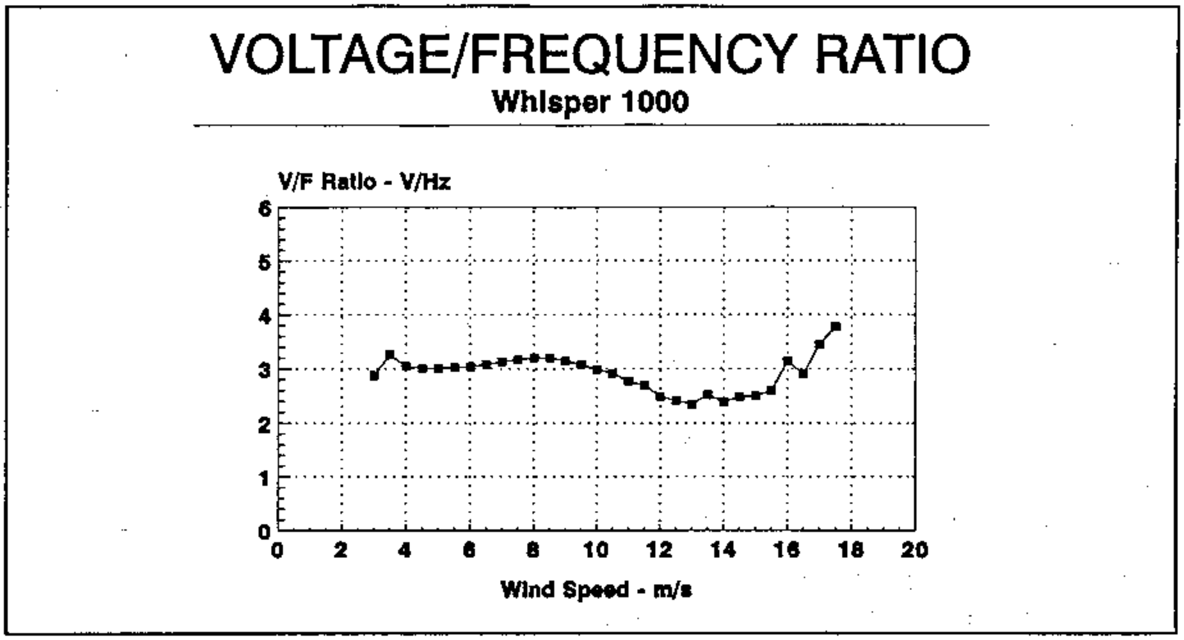

Figure 6 The voltage/frequency ratio for a 1000 W wind turbine while pumping from a depth of 45 m.

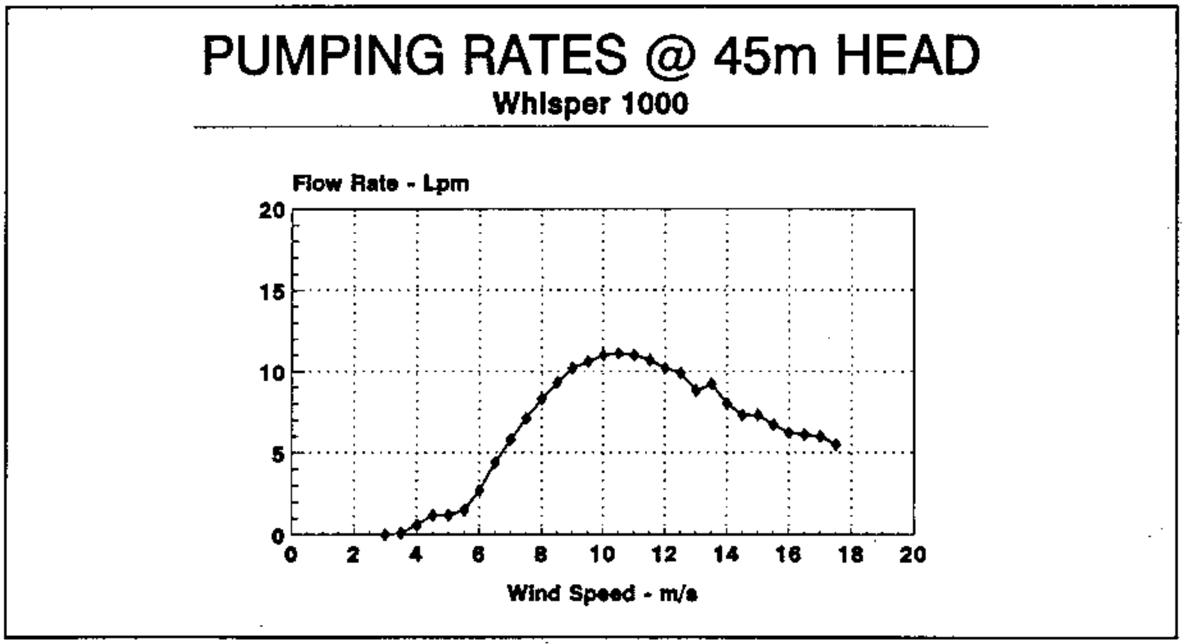

Figure 7 Water flow rates for a 45 m pumping depth using a submersible pump and 1000 W wind turbine.

CONCLUSIONS

A 1500 W wind-electric water pumping system that operates independent of the electric utility was operated at 7 different pumping heads ranging from 17 to 59 m. Performance data were collected for over 700 hours at each pumping head. During all these tests, the wind turbine, pump controller, electric submersible motor and pump required no maintenance. These systems experienced wind speeds in excess of 30 m/s. We feel that these machines reliable and robust enough to be installed in remote areas when the greatest need for livestock and domestic pumping occur. Average daily water volumes averaged 12,530 L/day with highest daily rates occurring in March and the lowest in August. Water volumes exceeded 10,000 L/day in all months except August.

A wind turbine with a rating of 1000 W was also tested at a pumping head of 45 m. The flow was not as high as expected because the unit did not start consistently at a wind speed of 5 m/s and the voltage and frequency were not as high as needed (or expected) to maintain the pump and motor at the proper operating speed. A new alternator installed near the end of the test period performed much better and it appeared that the original alternator was defective. This unit had two rotor blades constructed of aspen wood that were light weight and would easily stall when the system was loaded by the motor and pump. I recommend that the rotor blades be constructed of material that contains some weight so that the rotor will develop some inertia to maintain rotation when loaded with an electric motor. The heavier, three-bladed wind turbine did a much better job of starting the pump motors.

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